INTEGRATED BEAM DIAGNOSTICS SYSTEMS FOR HIT AND CNAO

A. Reiter, A. Peters, M. Schwickert
Gesellschaft für Schwerionenforschung mbH (GSI), Darmstadt, Germany

Abstract

An integrated system for beam diagnostics was produced at GSI for the heavy-ion cancer treatment facility HIT (Heidelberger Ionen-Therapie) of the Heidelberg university clinics. A set of 92 manifold beam diagnostic devices allows automated measurements of the main beam parameters such as beam current, profile or energy. The beam diagnostic subsystem is completely integrated in the overall accelerator control system and its timing scheme. This paper reports on the underlying design patterns for the abstraction of the beam diagnostic devices towards the control system. Event-counting devices, i.e. scintillating counters and ionization chambers, are presented as examples of the diagnostic devices in the synchrotron and high-energy beam transport section of HIT.

Additionally, it is shown that the well-defined building blocks of the beam instrumentation made it possible to prepare almost identical devices including the manual control software, to be used in the CNAO facility (Centro Nazionale Adroterapia Oncologica) presently under construction in Pavia, Italy.

INTRODUCTION

The heavy-ion cancer treatment facility HIT (Heidelberg Ion Therapy) is presently under construction at the university clinics in Heidelberg. The accelerator part includes a 7 MeV/u-Linac consisting of a four-rod RFQ-tank and an IH-structure. A synchrotron with a magnetic rigidity of Bρ=0.38-6.5 Tm will accelerate heavy ions (i.e. carbon, oxygen) up to 430 MeV/u. The medical part consists of two horizontal treatment areas and a gantry-section for 360° patient irradiations. For further technical details about HIT cf. ref. [1].

Works for the civil construction of the accelerator of the building were finalized by the end of 2005. The Low Energy Beam Transport (LEBT) section is mounted and all of the beam diagnostic (BD) devices are installed and commissioned. Acceptance tests of the ion sources started in April 2006, and the BD devices were already used to perform test procedures and commissioning of the LEBT section.

In the HIT project, the GSI BD group acts as contractor for the delivery of all beam diagnostic devices, including all mechanical parts, data acquisition (DAQ) systems as well as software to read out BD devices. Due to the high demands of a medical facility concerning performance and reliability, the basic guidelines for the layout of the BD systems were:

- use of commercial and standardized components wherever possible,
- supply of a reliable and robust manual control software for all BD devices,
- maximum integration of the DAQ system in the overall accelerator control system (ACS).

This report presents examples of BD elements for HIT and explains how a maximum integration in the ACS was achieved. Additionally, we outline the integration of the same building blocks into the Italian therapy project CNAO.

INTEGRATION OF BEAM DIAGNOSTICS IN THE ACS

The underlying design strategy for the software was, to use identical software for identical beam parameters to a maximum extent. Further, the same software modules for data acquisition should be used in both, the accelerator control system and the manual control software, i.e. modules used for commissioning and trouble-shooting purposes (s. below).

On the hardware side, standardized industrial solutions were preferred, wherever possible. Thus, for all DAQ systems, the PXI standard was chosen [2].

To comply with the adopted strategy, the various BD elements were grouped into seven logic device classes (see Table 1), i.e. classes of elements that measure the same beam parameter.

Table 1: Beam diagnostic device classes for HIT

Device class	BD elements
Profile measurement	Profile grid, Multi-wire proportional chamber
Event counting	Scintillating counter, ionization chamber, beam-loss monitor
DC-current	DC-transformer, Faraday-cup
AC-current	AC-transformer, Faraday-cup
Phase probe	Phase probe, RF coupling loop
Beam position	Beam position monitors
Optical diagnostics	Viewing screen, Isocenter Diagnosis

For example the device class "AC-current" contains 3 Faraday cups and 4 AC transformers. Pneumatic and stepper motor drives, and HV and gas flow control form an own class "command devices" that is independent of the measurement control of the mounted detector.

BD devices within a given class are treated in an identical manner and were therefore integrated into a common, stand-alone DAQ system with embedded controller. All device classes use similar hardware modules and PXI controllers. Communication with the DAQ system for configuration of measurements, data transmission and analysis, can be established by both, manual and accelerator control software, via an Ethernet link. From the point of view of the ACS the PXI controllers are transparent, i.e. the ACS communicates with a logical DAQ-layer. Independently of the ACS, the manual control software allows to check every function of a BD device and to read out all status bits. This software is intended for commissioning and trouble-shooting purposes and is typically installed on a laptop locally connected to the embedded controller of a DAQ system. However, online analysis, data storage or other time-consuming tasks are reserved for the ACS only.

For the control of power supplies, rf amplifiers and other time-critical components of the HIT accelerator, a second type of controller is used, the device control unit (DCU). All DCUs are controlled via Ethernet and synchronized by a real-time bus (RTB), which guarantees 10 ns timing accuracy [3]. DCUs and PXI controllers use an (almost) identical communication protocol, and can therefore be treated similarly from the ACS point of view.

For diagnostic measurements, dedicated timing DCUs with 32 programmable TTL output channels supply all necessary DAQ signals such as start or stop triggers as well as inhibit signals. The outputs are configured prior to a measurement.

Generally, measurements are initialised using VACC (Virtual accelerator) settings, stored in the database of the ACS, which precisely define all measurement parameters, e.g. pre-amplifier gains, integration times or the DCU trigger timing. Repeated execution of a VACC sequence automates measurements and a "trending" function for non-interceptive BD devices observes the long-term stability of important beam parameters at various locations during routine machine operation. The data of different DAQ systems is analysed simultaneously, to derive e.g. width and position of the beam from profile grids and, at the same time, multi-wire proportional chambers (MWPCs) or a viewing screen.

EXAMPLES OF DIAGNOSTIC DEVICES

In this section, four device classes "DC- and AC-current", "profile measurement" and "Event counting" are presented as examples of beam diagnostic devices used in the Linac, synchrotron and HEBT (high-energy beam transport) sections of HIT.

The measurement of the beam current in the LEBT/Linac section is performed, using the device classes "DC-" and "AC-current". These two device classes control altogether 7 Faraday-cups, 3 AC-Transformers and 2 DC-transformers. Because the two ECR ion-sources of HIT produce a DC beam, each of the two LEBT branches is equipped with 2 DC-type GSI Faraday-cups and one commercial DC-transformer [4]. The signals are recorded by 200kSa/s ADC-boards (12 bit resolution) in the PXI standard [2] and a 300 MHz PXI controller collects the data and builds the interface towards the ACS.

The 300µs-macropulses produced for injection in the 400 keV RFQ are observed by means of the "AC-current" device class, containing 3 AC-type Faraday-cups and 3 AC-transformers [5]. The GSI-built preamplifiers for Faraday-cups (AC-type) and AC-transformers use an auto-zero function to minimize any drift of operational amplifiers. Both BD elements are sampled with 10MSa/s ADC-boards and 12 bit resolution.

Any time-resolved measurement with BD devices of the two device classes "DC/AC current" can be visualized, compared and analyzed online. A "trending" function is also implemented, which shows the long-term trend of the beam current by displaying the mean value of the beam current over a selectable period of time. This feature is especially suitable for logging of important machine parameters. Additionally an online transmission measurement is implemented.

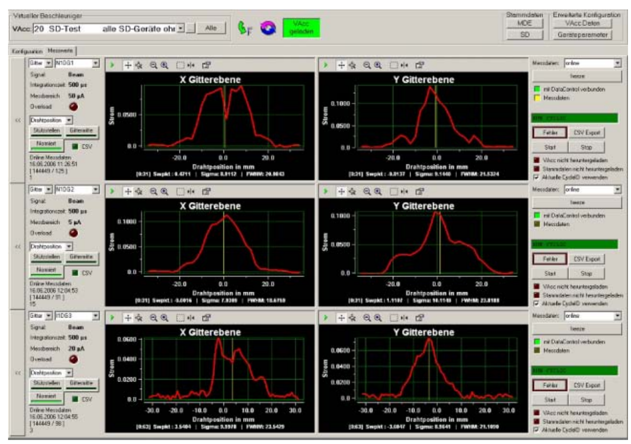

Figure 1: Beam profiles measured during the LEBT commissioning of the HIT facility.

The device class "profile measurement" groups together 8 profile grids (LEBT and MEBT sections) and 13 MWPCs of the HEBT section, where beam intensities are significantly lower. The profile grids contain 64 horizontal and 64 vertical wires. A special I/U-converter and multiplexer unit digitizes every wire signal independently and supplies the current information to so-called "profile grid control units", that can address up to 8 profile grids [6]. Fig. 1 shows a screenshot of a measurement with 3 profile grids. In addition to the x- and y-distributions, centre and width of the beam are monitored online. Again a trending function facilitates ion optical procedures like focusing and beam alignment. Further, these values can be transferred as input parameters to the theoretical accelerator model.

The device class "Event counting" contains 5 scintillating counters, 6 beam-loss monitors and 13 ionization chambers. The detector signals are digitized using 8-channel 32-bit scalers with a standard trigger rate of 10 kHz. For high-resolution measurements selected scaler channels can be switched from their standard IRQ-mode to DMA-mode, enabling trigger rates of up to 15 kHz (see ref. [7] for details).

Fig. 2 shows a photograph of the vacuum feed-through with its pneumatic drive (top) and the scintillating counter (bottom). The cylindrical vacuum feed-through has 50 µm stainless steel foil windows at the entry and exit direction of the ion beam. Thus the detector, during normal operation situated inside the cylindrical feed-through, may be dismounted without breaking the vacuum.

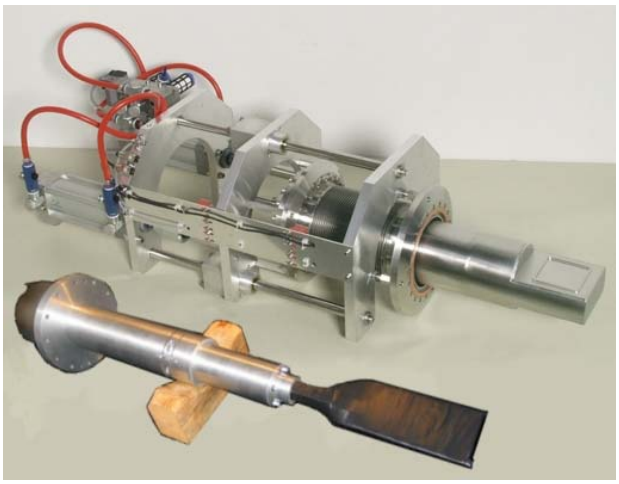

Figure 2: Vacuum feed-through (top) and scintillator (bottom), the active area is covered with black tape.

BEAM DIAGNOSTICS FOR CNAO

A second cancer therapy facility, designed by the Italian foundation CNAO [8], is currently under construction in Pavia, 30 km south of Milan. The facility is located in close proximity to the San Matteo hospital which offers a well-suited medical infrastructure for the new treatment facility. After the first construction phase 3 horizontal treatment places will be available. In a second phase two gantries may be added to the facility.

GSI contributes to CNAO by delivering a linear accelerator (Linac) identical to the one designed for the HIT facility. To facilitate commissioning and integration of the Linac system into the accelerator facility, an independent stand-alone control system and all necessary DCUs and BD devices were included into the delivery.

The GSI BD group is responsible for production and tests of the following diagnostic components:

- 7 profile grids for monitoring of the beam profile at the entrance of the Linac and in the medium energy beam transport line to the synchrotron,
- 2 AC-transformers and electronics for 5 Faraday-cups,
- a foil stripper, with a ladder for ten carbon targets, mounted on a stepping motor controlled linear feed-through, and
- 4 phase probes for measurements of the beam energy after the Linac and the phase relations between particle bunches and radiofrequencies of the two Linac amplifiers or the debuncher in front of the synchrotron.

Due to the modular structure, hardware and software of the three DAQ systems for beam current, profile and energy could be easily adjusted to meet the requirements of the CNAO facility. In May 2006 first tests of CNAO ACS modules with timing DCUs were successful and integration work will continue with the phase probe DAQ systems during the upcoming RFQ tests.

So far the DAQ systems were used with the manual control to test the HIT-RFQ at GSI. Figure 3 shows the compact beam line with the end flange of the RFQ tank on the right, followed by two quadrupoles and BD devices: three phase probes, one AC-transformer, one profile grid and a Faraday-endcup.

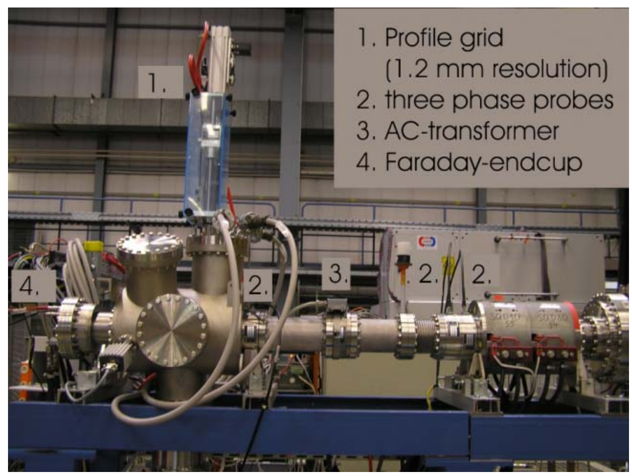

Figure 3: View of the BD devices in the test bench for HIT- and CNAO-RFQ.

The electrostatic pick-ups are built in 50 Ohm geometry. Their signals are amplified by a high bandwidth, variable-gain amplifier (1 GHz, 20-60 dB) and then sampled with 4 cPCI Digitizer-boards, with a rate of 4 GSa/s and 8-bit resolution [9]. The beam energy is determined from the phase probe signals by the time-of-flight method.

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